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Confinement Effect of Geo-grid and Conventional Shear Reinforcement Bars Subjected to Corrosion

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ABSTRACT

An experimental study was performed to examine the effects of polyester geo-grid as a shear reinforcement bar for corroded and uncorroded reinforced concrete beams. The main aim of this study was to investigate the effect of geo-grids on flexural strength, moment-curvature, bond–slip and crack patterns for uncorroded and corroded reinforced concrete beams. For each parameter, a geo-grid confinement technique was compared with conventional reinforced concrete beams as a function of corrosion level. The experimental program consisted of testing ten reinforced concrete beams for two different configurations of shear reinforcement bars at six different corrosion levels (0% and approximately 2, 3, 5, 6, and 9%). Test specimens were subjected to an accelerated corrosion method to corrode the reinforcement bars using a full-scale corrosion pool. Actual corrosion levels were obtained from fully extracted reinforcement bars by breaking the concrete. At the same overall corrosion levels which were differed at longitudinal and transverse reinforcement bars at the same applied corrosion current time for different RC beams. Obtained actual corrosion levels with the aid of fully extracted reinforcement bars from concrete provided to examine the effect of corrosion levels by considering the type of reinforcement bars. The results indicated that the performance of the polyester geo-grid was very poor compared to conventional steel stirrups, even at this stage of corrosion. It was found that the utility of a geo-grid as shear reinforcement bars in reinforced concrete beams is not proper.

1. Introduction

The corrosion of steel reinforcement bars is an important factor in the structural performance of reinforced concrete (RC) buildings. Premature deterioration caused by corrosion not only affects structural performance, but also causes economic problems within the service life of the structures. Many studies have been carried out to define the effects of corrosion on structures. The cracking of concrete under volumetric expansion (e.g., [1–4]), bond–slip relationships (e.g., [5–6]), time-dependent structural performance levels (e.g., [7–10]), flexural strength of corroded RC beams (e.g., [11–14]), and strengthening of deteriorated members (e.g., [15–17]) have been widely studied. The reduction in structural performance levels of RC structures because of corrosion has motivated researchers to find new materials to use instead of conventional longitudinal and transverse reinforcement bars (i.e., fiber reinforced polymer bars), especially when RC buildings are located in high-chloride environments. In the available literature, one of the latest materials to be used for RC members is called a geo-grid. Geogrids are polymeric products formed by joining intersecting ribs which are produced from polymers (e.g., polypropylene, polyethylene and polyester). They are manufactured and classified as either biaxial or uniaxial. Uniaxial geogrids exhibit high tensile strength in the machine direction which has enough strength to maintain the structure of the apertures. Biaxial geogrids exhibit the same tensile strength in both machine (MD) and cross-machine (CMD) directions. A study done by Maxwell et al. [18] indicated that biaxial geogrids cannot provide a uniform tensile strength when they are subjected to tension in different directions. Studies on geo-grids have generally focused on increasing the bearing capacities of foundations (e.g., [19–24]), asphalts and pavements (e.g., [25–28]). With the increased interest in geo-grids, they have also begun to be used for RC members, either as longitudinal or transverse reinforcement bars (e.g., [29–31]). The available literature also suggests that geo-grid confinement may be an alternative solution because of its efficiency in corrosive environments. As geo-grids do not corrode, they may provide alternative solutions to conventional transverse reinforcements which are the subject of the present study. Although few studies have suggested using geo-grids as an alternative material, test results obtained from geo-grid indicated that it could be used as an alternative material to conventional bending or shear reinforcement bars. However, the suggestion of using geo-grids as an

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Table 1
Mechanical properties of materials.

Material	Yield strength (MPa)		Rupture strength		Strain at yielding (mm/mm)		Strain at rupture (mm/mm)		Elastic modulus (MPa)	
Steel bar	8 mm	16 mm	8 mm	16 mm	8 mm	16 mm	8 mm	16 mm	2×10^5	
	511	459	612 MPa	579 MPa	0.0026	0.0023	0.036	0.011		
Geo-grid	–	–	MD	CMD	–	–	MD	CMD	MD	CMD
			110 kN/m	30 kN/m			0.18	0.16	610	200

alternative material suffers from a lack of information on RC members. First, previous studies on the performance of geo-grids compared them with plain concrete (i.e., without reinforcement bars). Second, the tested specimens had smaller sizes than real conditions of RC structures.

One study regarding geo-grids with and without steel fiber in plain concrete beams was conducted by Chidambaram and Agarwal [29]. In that study, one and two layers of geo-grids were tested under flexural tests with specimens of 500 mm in length. Chidambaram and Agarwal [29] compared geo-grid specimens with plain concrete. Other studies (e.g., El Meski and Chehab [30], Itani et al. [32]) used geo-grids as bending reinforcement bars with scaled RC beams, and also compared the geo-grid specimens with plain concrete. As the geo-grid comparisons were based on plain concrete members, the test results were extremely positive for the geo-grids. Chidambaram and Agarwal [31] also investigated the effect of geo-grids as a confinement material in concrete used with steel fibers. In that study, the performance of geo-grids without steel fibers was not investigated. Therefore, the suggestion of using geo-grids as an alternative material for RC members is limited, as it has only been compared with plain concrete or scaled members with additive materials. Moreover, given that concrete has a limited deformation capacity, it cannot allow the geo-grid to undergo large deformation which has low elastic modulus. In the current study, the used mechanical properties of the geo-grid were similar to the type of geo-grid used by Chidambaram and Agarwal [31].

In the available literature, the suggestion of using geo-grids in structural members brings about another parameter that has not been studied. The confinement effect provided by conventional transverse reinforcement bars affects the bond–slip relationship. None of the previous experimental studies have considered the effect of geo-grids on the bond–slip relationship. The bond–slip relationships, which affect the displacement of a structure during an earthquake, are an area where there is a lack of information regarding the use of geo-grids. The authors of this paper performed a series of tests to investigate the performance of geo-grids used as shear reinforcement bars for full-scale RC beams with and without polypropylene fibers [33]. In that study, the test results showed that, in contrast to previous studies, the performance of geo-grids was very weak and limited by the ratio of additive materials when compared with conventional RC beams. Moreover, it was observed that geo-grids were affected by the heat that they released themselves, making them impractical in construction site conditions.

To the best knowledge of the authors no study has been performed to investigate the effect of geo-grids with corroded longitudinal reinforcement bars. The behavior of geo-grids compared to corroded conventional transverse reinforcement bars is unknown. Therefore, the suggestion of using geo-grids as alternative confining reinforcement bars under the effect of corrosion requires new research to define their utility in RC members. In this study, a series of experimental tests were performed to investigate the effect of geo-grids used as transverse reinforcement bars for uncorroded and corroded RC beams. Conventional transverse reinforcement bars and confinement provided with geo-grids were investigated under flexural tests. The tests results were evaluated in terms of the flexural strength, load–deflection, bond–slip relationships, and crack patterns for uncorroded and corroded RC specimens.

2. Experimental program

2.1. Material properties and casting concrete

For the current study, deformed reinforcement bars were used for the conventional RC beams. A uniaxial geo-grid which was made of high tenacity polyester yarn was used as a complete replacement for conventional transverse reinforcement bars. The thickness of the geo-grids at machine and cross-machine directions was 1 mm in equivalent solid thickness. The width of the geo-grids at machine and cross-machine directions was 5 and 2 mm, respectively. The dimensions of the square apertures were 25 mm. The mechanical properties of the conventional reinforcement bars and geo-grids are given in Table 1. In Table 1, tensile tests for conventional reinforcement bars and geo-grid were done according to the described standards by ASTM D6637-10 [34] and ASTM A370 [35], respectively.

Before pouring the concrete, the surface of each reinforcement bar was cleaned and the initial mass of the reinforcement bars for each specimen was recorded. As the corrosion process occurs over a long-time period in which the time-varying concrete compressive strength would also change, the test specimens were cured for three months (Fig. 1) by placing them into a pool to prevent any disturbance for the changes in concrete compressive strength. Compressive strengths of the cylindrical concrete specimens were carried out with related specification by ASTM C39 [36]. The recorded cylindrical compressive strength of concrete after three months was 30 MPa.

2.2. Section properties and configuration

For the current study, the specimens were coded as C and G. The letter C defines the conventional RC beams, where longitudinal and shear reinforcement bars were constructed with steel bars. Both longitudinal and shear reinforcement bars were corroded in group C. The letter G defines the RC beams, where confinement was provided by a geo-grid (longitudinal reinforcement bars were constructed with steel bars and transverse steel bars replaced with geo-grids). Thus, in type G,

Fig. 1. Curing process of RC beams.